Mechanical Analysis of Buried Gas Pipe Line of Different Grades of Steel at a Depth under the Influence of Sub-Surface Blast Loading

V Ravi Kiran[1], P Manoj[2]

[1]M. Tech, Assistant Professor, Department of Civil Engineering
[2]M.E, Assistant Professor, Department of Civil Engineering

---***---

ABSTRACT:- The transportation of resources like oil, gas, water etc., is being done mainly through underground pipe lines of different materials based on the material being transported. This research has been inspired by security concerns due to the recent activities happening as a threat to the oil and natural gas transportation sectors. The present work is done on the study of behavior of underground pipe lines under the effect of blast loading at a certain depth from the ground surface using ANSYS-Explicit Dynamics. The study of this work is validated from the recent studies done by (M. Mokharti, A. Alavi Nia). A combined Eulerian-lagrangian (CEL) method was developed for full coupled 3D finite element model. And the steel pipe is modeled in simplified Johnson cook model for the mechanical behavior of the pipe and air is considered for accuracy. Hence the work is further being carried with high grade steels like X-65, X-70 and the results are satisfactory such that as the grade of the steel increases the amount of strain and deformation produced are decreasing gradually. The observations from the study shows that the change in diameter-to-thickness ratio (D/t) and the pressure in the pipe line is varied from non-pressurized to pressurized in the pipe line and behavior varies under the blast load.

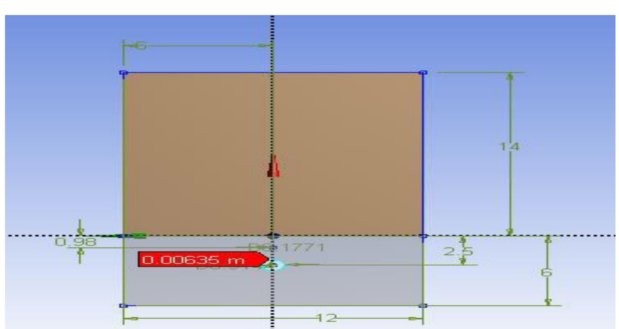
Key Words: ANSYS-Explicit Dynamics, combined Eulerian-lagrangian (CEL), diameter-to-thickness ratio (D/t), X-65, X-70.

Introduction:

There are number of methods available to determine the responses of underground structures to blast loads. These are: i) the analytical methods, and ii) the numerical methods using numerical tools. The problem of analytical method is that the solution allows only a small elastic response or limited plastic response and does not allow for large deflection and may lead to unstable responses. To overcome these problems, the finite element analysis paves the way towards a more rational blast resistance design. Though the drawback is the time and expertise required in pre- and post-processing for a given structural system this can be minimized by thorough work.

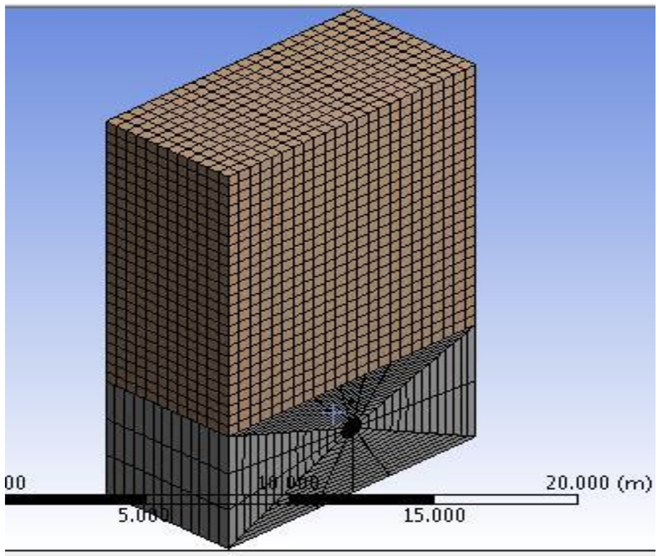
Dimensions and Mesh:

A typical size for oil and gas transmission pipelines, 914.4 mm (36 in.) is supposed to be the outer diameter of the pipeline. Four different values of 6.35 mm ((1/4) in.), 9.53 mm ((3/8) in.), 12.7 mm ((1/2) in.), and 15.88 mm ((5/8) in.) are considered for the pipe's wall thickness, corresponding to diameter-to-thickness ratios (D/t_p) of 144, 96, 72, and 57.6, respectively. The dimensions are developed based on a parametric analysis carried out in the current study so that larger dimensions do not influence the results. TNT of weight 10kg is placed at a depth of 98cm from the ground according to the field tests of Ambrosini et al. providing the opportunity to validate the results obtained from the present study.



Dimensions of the complete model

The pipeline is modeled with Lagrangian mesh, whereas the explosive charge, the air and the soil are modeled with Eulerian mesh. Simulating the process of the crater formation is very troublesome with the continuous Lagrangian FEM mesh due to the fact that the soil is ejected away from the blast in the process. Because of large deformation, the Lagrangian mesh tangles leading the results to deviate. Using CEL method in the current study has contributed this trouble to be solved. Furthermore, considering the air in the model has led detonation products cloud to be formed correctly.



CEL full coupled model and meshing

Simulation:

The simulation was carried out in two steps. In the first step, the gravity force and operating pressure of pipeline were exerted to the model and in the second step, detonation took place. The interface between the surrounding soil and the outer surface of the steel pipe is simulated with the Frictional Contact algorithm. The contact is created between Lagrangian mesh surfaces and Eulerian material surfaces, automatically computed and tracked during the analysis using default contact algorithms.

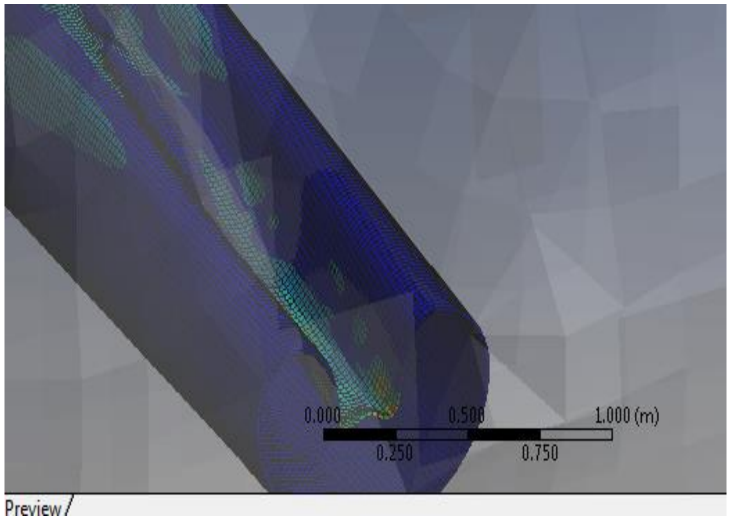
If the design factor of 0.72 is considered the maximum operating pressure (MOP) is defined in the following form

$P_{max}=0.72\times (\sigma_y \frac{2tp}{D})$ …………………… (1)

where σ_y is the yield stress of the pipe material, t_p is the pipe thickness and D is the outer diameter of the pipe. Simulation is done for each pressure condition and at each thickness. The maximum operating pressure for X-70 steel is calculated by using the equation (1)

When we consider the Equivalent strain in steel pipes, we can notice that it takes place at the crown of the pipeline. Maximum equivalent strain, at the beginning of deformation of the pipeline, occurs exactly beneath the explosive charge. Then, when the time progresses the location of maximum equivalent strain moves on the crown and goes farther from crown and eventually is located at the end of deformation zone along the pipeline and at the crown of it. This process of deformation is the predominant mode of deformation in the non-pressurized pipelines under a close-in high-rate explosive loading is understood.

Decrease in diameter-to-thickness ratio contributes the length of deformation zone and the amount of cross-sectional deformation of pipe to decline. On the other side, the amount of deformation pertains significantly to operating pressure so that there are negligible deformations in pipelines with maximum operating pressure. Consequently, as deformation of pipeline is reduced the location of maximum equivalent strain approaches the point beneath the explosive charge and at the crown of the pipelines

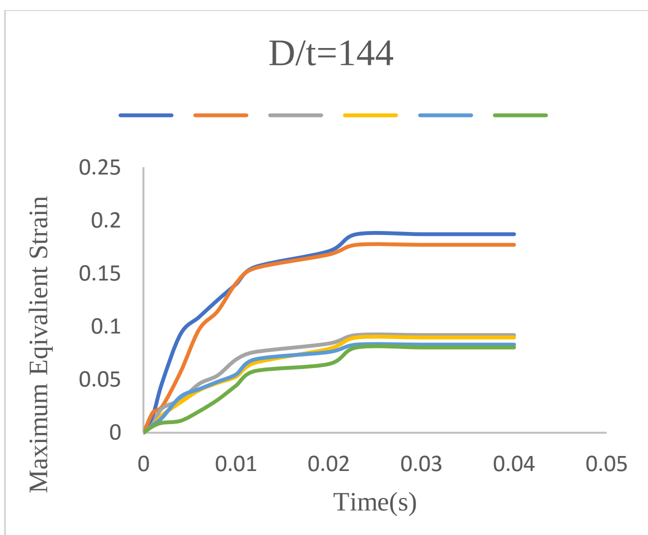


Pipe under the influence of sub surface blast loading

Results:

The results in this paper are validated from the previous publications and results of field tests held. Since the use of Ansys gives the satisfactory results, the analysis of the pipe line with similar pressure conditions and D/t thickness conditions for higher grade steel pipe line.

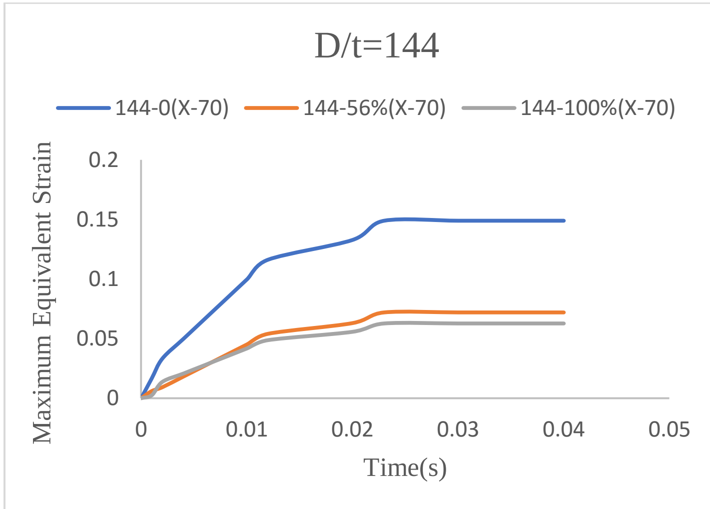
The results are compared and presented in graphical representation in this section. 0,56,100 represents the pressure conditions from non-pressurized to pressurized conditions.



Validation of results by Comparison (pp-Published Paper, Th- Thesis)

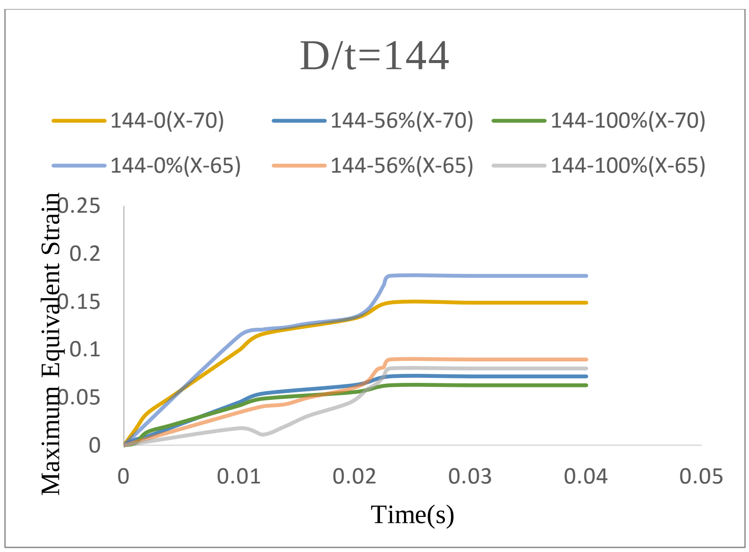
By observing the graph shown above, and the results are validated upto 90% of the field tests and published paper. The same comparisons are done for D/t values of 96,72,57.6 conditions and in each case the results are validated upto 90%.

The above results show that Ansys with automatic generated mesh gives similar results, hence analysis is done for higher grade steel X-75.



Variation of X-70, D/t=144 pipe under blast loading at different operating pressure

The same analysis is done for the above grade of steel and at different D/t conditions for various operating pressures. The analysis is also for same D/t ratio of X-65 and X-70 grade steels at different operating pressures. The results are shown in the graphs below.



Comparison of variations of X-65 and X-70, D/t=144 under blast loading at different operating pressure

Conclusion:

From the above validations and results obtained by comparing the data from field tests and papers published we can conclude that the modeling and the auto generated mesh by the use of ANSYS- Explicit Dynamics, the results are validated upto 90% of the previous data. By this conclusion the work is further carried out for the increasing the grade of the steel from X-65 to X-70. The whole analysis with different D/t ratios and pressure conditions, the results obtained in each case is compared between X-65 and X-70 grade steels and the results shows that higher the grade of the steel used the amount of strain or deformation produced on the surface of the crown decreases and other parameters like equivalent stress and strains, directional strains are reduced for higher grade of steel. Even the Youngs modulus of the different grade of steel remains same, the chemical compositions of the steel vary. Change in chemical compositions influence the mechanical characteristics of the material.

REFERENCES:

[1] Bragov, A.M., Lomunov, A.K., Sergeichev, I.V., Proud, W., Tsembelis, K., and Church, P. (2005). "A method for determining the main mechanics properties of soft soils at high strain rates (103-105s-1) and load amplitudes up to several Giga Pascal's," Technical Physics letters., 31(6):530-531

[2] B. Luccioni, D. Ambrosini, G. Nurick, I. Snyman, "Craters produced by underground explosions, Computers & Structures", 87 (2009) 1366–1373.

[3] Das, Braja M. (1983), Advanced soil mechanics, 1st ED., Hemisphere Publishing Corporation., Washington, New York, London.

[4] E.D. Esparza, P.S. Westine, A.B. Wenzel, Pipeline response to buried explosive detonations, Southwest Research Institute Report to the American Gas Association, AGA Project, PR-15- 109, 1981.

[5] E. El-Danaf, M. Baig, A. Almajid, W. Alshalfan, M. Al-Mojil, S. Al-Shahrani, Mechanical microstructure and texture characterization of API X65 steel, Materials & Design 47 (2013) 529–538.

[6] Bessette, G. C. "Coupled Euler – Lagrange modeling of buried structure response to blast loading", 75–78.